# Subsurface Drip Irrigation Lateral Spacing and Management for Cotton in the Southeastern Coastal Plain

C. R. Camp, P. J. Bauer, P. G. Hunt

**Abstract.** *The cost of drip irrigation can be reduced by using both wider lateral spacings and the same laterals for multiple years, as with subsurface placement. Multiple, low-rate fertilizer and water applications may reduce N fertilizer needs by improving efficiency and limiting the potential for leaching. The combination of these technologies may make drip irrigation of cotton profitable. Four years of continuous cotton and two years of cotton rotated with peanut were evaluated. Two subsurface drip irrigation lateral spacings (every row, 1 m, and alternate furrow, 2 m) and three sidedress-nitrogen methods (STD, single application of 112 kg/ha; INC, 112 kg/ha in five equal applications; and GOS, applications determined by GOSSYM/COMAX) were evaluated for cotton during 1991-1994. Two of the sidedress-nitrogen methods (STD and GOS) were evaluated for a rainfall-only treatment. Lint yields did not differ between the lateral spacings in any year. Yields for irrigated treatments were 16 and 65% greater than rainfall-only yields in 1992 and 1993, respectively. The GOSSYM/COMAX-managed nitrogen treatment received 30% less nitrogen fertilizer than other treatments, but had similar lint yield. Several fiber physical properties were affected by irrigation and nitrogen, but these effects were small and inconsistent. For continuous cotton, or cotton rotated with peanut, the wider lateral spacing is preferred to the every-row spacing because of its lower initial cost (about 30%). The combination of lower system cost, longer system life, and lower N-fertilizer requirements could make subsurface drip irrigation of cotton profitable for southeastern Coastal Plain soils, and reduce the potential for ground water contamination.*
***Keywords.*** *Lateral spacing, Fiber quality, Tensiometers, Nitrate, Crop growth model.*

In the southeastern Coastal Plain, crop yields are reduced by drought stress about every other year because of poor rainfall distribution and low water storage in coarse-textured soils (Sheridan et al., 1979). Cotton yield is dependent upon the production and retention of bolls, both of which can be decreased by water stress (Guinn and Mauney, 1984). Additionally, income produced by cotton depends on yield and its value based on fiber physical properties. Little is known about the effect of plant water status on the physical properties of cotton fibers in the southeastern USA. However, even short periods of water stress during susceptible stages could cause shorter fibers and less-developed cell walls in bolls (Ramey, 1986).

To reduce the economic impact of yield reduction during these drought periods, many cotton growers consider irrigation. Sprinkler irrigation is most often the system used for irrigation of agronomic crops in the southeastern USA; however, high-frequency drip irrigation can prevent cyclical water stress that is often associated with other irrigation systems (Radin et al., 1989). Development of economically viable drip irrigation systems could improve the precision of water placement and reduce energy requirements. Two major disadvantages of traditional surface drip irrigation with laterals placed in every row are the large amount of tubing (laterals) required and the annual cost of either purchasing many new system components or retrieving, storing, and re-installing used laterals. Camp et al. (1993b) demonstrated in cotton that alternate-furrow (2-m spacing) placement was equal to every-row (1-m spacing) placement for laterals placed on the soil surface in the southeastern Coastal Plain. On a coarse-textured soil in Arizona, cotton yields were comparable for laterals placed either every row (1-m spacing) or every other row (2-m spacing), but were 30% lower for laterals placed every third row (3-m spacing) (French et al., 1985).

Drip irrigation systems with wider-spaced laterals buried below the tillage zone require less material initially and use the same material for multiple years. Drip irrigation laterals installed 0.2 to 0.3 m below the soil surface have been used successfully in commercial applications for cotton (Tollefson, 1985), and in research applications for corn (Camp et al., 1989) and fruits and vegetables (Bucks et al., 1981; Phene et al., 1983; Camp et al., 1993a).

Profitability of irrigation in humid areas is also affected by the manner in which irrigation is scheduled and how efficiently rainfall is used. Previous research has shown that less irrigation was needed to obtain equal yield when

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managed with the GOSSYM/COMAX cotton growth model than with tensiometers (Camp et al., 1993b). Although not designed specifically for irrigation scheduling, crop growth models such as GOSSYM/COMAX (Baker et al., 1983; Lemmon, 1986) for cotton may be used for water and N-fertilizer management by using the water- and nitrogen-stress indices calculated by the model and their predicted impact on yield. With subsurface drip irrigation systems, the potential exists for improved profitability and reduced environmental contamination if this model can be used to manage applications of small amounts of both water and N fertilizer as needed by the crop.

The objectives of this study were to (1) determine the effect of irrigation on cotton yield and fiber properties; (2) compare lateral spacing for cotton yield and fiber properties; and (3) evaluate three nitrogen-fertilizer management methods in a cotton-peanut rotation.

## MATERIALS AND METHODS

The study was conducted on a 1.2-ha site of Eunola loamy sand (Aquic Hapludults) near Florence, South Carolina. Drip irrigation laterals were installed 0.30 m below the soil surface of cotton on 1.0-m rows, either directly under each row (ER) or under alternate furrows (midpoint between rows) (AF). A schematic diagram of the two lateral spacings is shown in figure 1. Three sidedress-nitrogen treatments (all applied via the irrigation system) included (1) a single N application of 112 kg/ha, as recommended by the Clemson University Cooperative Extension Service (STD), (2) the same amount of N as in the STD treatment but applied in five equal weekly increments (INC), and (3) periodic applications (11-23 kg/ha N) based on GOSSYM/COMAX (GOS). All combinations of the two lateral spacings and the three sidedress-N methods, plus rainfall only (RAIN) for the STD and GOS sidedress N methods, comprised the eight treatments (table 1). Additionally, all treatments were included in the cotton phase of two crop rotations, continuous cotton and a peanut-cotton rotation, where

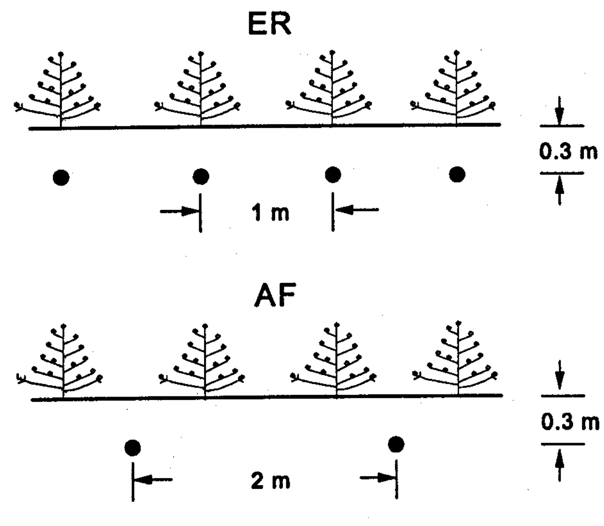


**Figure 1–Schematic diagram of two subsurface drip irrigation lateral spacings. ER = subsurface lateral under every row and AF = subsurface lateral under alternate furrows. Cotton rows are spaced 1 m apart. Open circles indicate lateral locations.**

**Table 1. Treatment combinations for irrigation and nitrogen with cotton in Florence, S.C., during 1991-1994**

| Nitrogen | Irrigated | | | | | |
|---|---|---|---|---|---|---|
| | AF† | | ER | | RAIN | |
| Treatment* | C/C | C/P | C/C | C/P | C/C | C/P |
| GOS | √ | √ | √ | √ | √ | √ |
| INC | √ | √ | √ | √ | No | No |
| STD | √ | √ | √ | √ | √ | √ |

* Codes for N-sidedress treatments are GOS = GOSSYM/COMAX, INC = incremental, and STD = standard.

† Lateral location/spacing and crop rotation treatment codes are AF = irrigation lateral below alternate furrows (2-m spacing), ER = irrigation lateral below each row (1-m spacing), and RAIN = rainfed (no irrigation); C/C = continuous cotton and C/P = cotton and peanut in rotation.

peanut was grown in 1991 and 1993 and cotton was grown in 1992 and 1994. The experimental design was a randomized complete block in a split-plot arrangement with four replications. Main plots were rotation, and sub-plots were the irrigation by N-fertilizer method combinations. The cotton cultivar, PD3, was planted on 22 May 1991, 14 May 1992, 12 May 1993, and 19 May 1994, and all treatments were hand-thinned to a population of 85,000 plants/ha. Each plot was 15 m long and 8 m wide, which provided eight rows spaced 0.96 m apart.

Sidedress nitrogen (30% UAN solution) was applied at different intervals via the irrigation system. Sidedress nitrogen for the RAIN-STD and RAIN-GOS treatments was applied via an irrigation system using the same type lateral as used for the irrigated treatments, but was located on the soil surface adjacent to each row. Specific nitrogen application dates and amounts for all years are reported in table 2. GOSSYM/COMAX simulations were not made for the rainfed condition; therefore, sidedress-N applications for the RAIN-GOS treatment were the same as for both irrigated GOS treatments.

Gauge-type tensiometers were installed in the row at depths of 0.3 m, 0.6 m, and 0.9 m in the ER-GOS and AF-GOS treatments only. Tensiometers were serviced as required, and readings were recorded three times each week. Meteorological parameters were measured at a weather station located adjacent to the experimental area. Seasonal rainfall was computed for the period between planting and two weeks prior to first harvest.

Growing-season rainfall, irrigation, and total water amounts for both irrigation lateral spacings during the four years of the study are included in table 3. Daily rainfall and

**Table 2. Sidedress fertilizer-N application amounts to cotton on a southeastern Coastal Plain soil during 1991-1994**

| Year | N Treat-ment | Weeks After Planting 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | Total N* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | (kg/ha) | | | | | | | | | | | |
| 1991 | GOS† | — | 11 | 11 | 11 | 23 | 11 | — | — | — | — | — | 79 |
| | INC | — | 22 | 22 | 23 | 22 | 23 | — | — | — | — | — | 124 |
| | STD | — | 56 | 56 | — | — | — | — | — | — | — | — | 124 |
| 1992 | GOS | — | — | — | 11 | 23 | 11 | 11 | 11 | — | — | — | 79 |
| | INC | — | — | 22 | — | 23 | 22 | 22 | 23 | — | — | — | 124 |
| | STD | — | — | 56 | 56 | — | — | — | — | — | — | — | 124 |
| 1993 | GOS | 11 | — | — | 11 | — | — | 23 | — | — | 11 | 11 | 79 |
| | INC | 22 | 22 | — | 23 | 22 | 23 | — | — | — | — | — | 124 |
| | STD | 112 | — | — | — | — | — | — | — | — | — | — | 124 |
| 1994 | GOS | — | — | — | 11 | — | 11 | — | 11 | 23 | 11 | — | 79 |
| | INC | — | — | 22 | 22 | 23 | 22 | 23 | — | — | — | — | 124 |
| | STD | — | — | 112 | — | — | — | — | — | — | — | — | 124 |

* Includes 12 kg/ha N preplant broadcast application.

† Treatment codes for N-sidedress treatments are as follows: GOS = GOSSYM/COMAX, INC = incremental, and STD = standard.

irrigation events for all years are shown in figures 2 and 3. Total growing season rainfall was greater in 1994 (684 mm) and 1992 (589 mm) than in 1991 (418 mm) and 1992 (331 mm), but seasonal distribution was more uniform in 1994 and 1991. Much of the rainfall (63%) in 1992 occurred late in the growing season (mid-August through October). Rainfall patterns for 1991 and 1993 were very different from those for 1992. The small difference in seasonal irrigation amounts among lateral spacings in 1993 resulted from accumulated small differences in individual irrigation applications during the growing season (table 3).

**Table 3. Irrigation and total water amounts for five water management-crop rotation treatments during 1991-1994**

| Lateral Spacing* | Crop Rotation* | 1991 Irrig | 1991 Total† | 1992 Irrig | 1992 Total | 1993 Irrig | 1993 Total | 1994 Irrig | 1994 Total |
|---|---|---|---|---|---|---|---|---|---|
| | | mm | | | | | | | |
| AF | C/C | 57(7)‡ | 475 | 90(9) | 679 | 136(19) | 467 | 26(4) | 708 |
| AF | P/C | --- | --- | 85(9) | 672 | --- | --- | 26(4) | 708 |
| ER | C/C | 57(7) | 475 | 90(9) | 679 | 130(19) | 461 | 24(4) | 706 |
| ER | P/C | --- | --- | 85(9) | 672 | --- | --- | 24(4) | 706 |
| RAIN | | --- | 418 | --- | 589 | --- | 331 | --- | 684 |

* Lateral spacing and crop rotation codes are defined as follows: AF = irrigation lateral below alternate furrows, ER = irrigation lateral below every row, RAIN = rainfall only, no irrigation, C/C = cotton/cotton rotation, and P/C = peanut/cotton rotation.
† Total water amounts include growing season rainfall amounts.
‡ Numbers in parentheses refer to the number of irrigation events during the growing season.

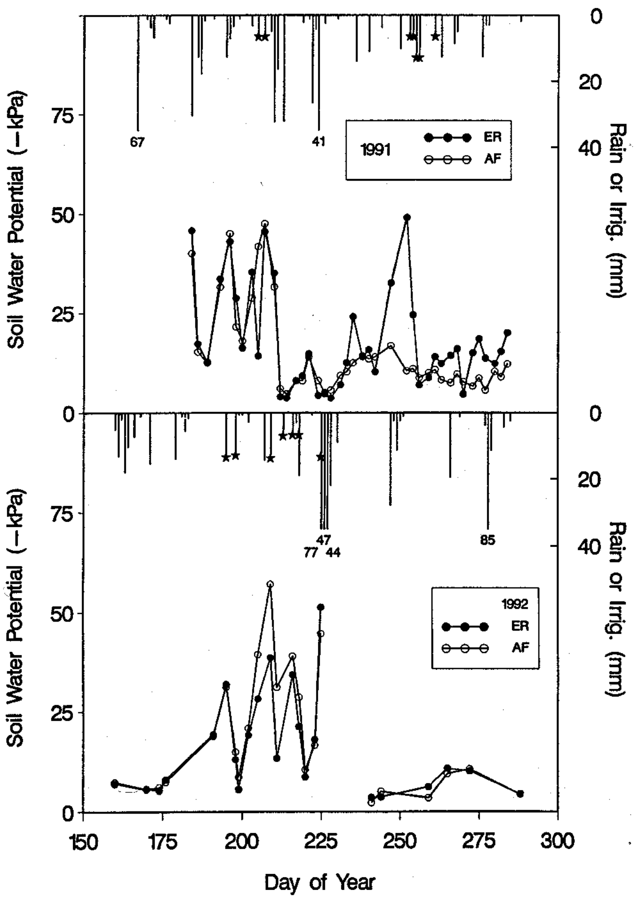


**Figure 2–Soil water potential at the 0.30-m depth and daily rainfall and irrigation amounts for two drip irrigation lateral spacings in cotton during 1991 and 1992. Stars indicate irrigation events.**

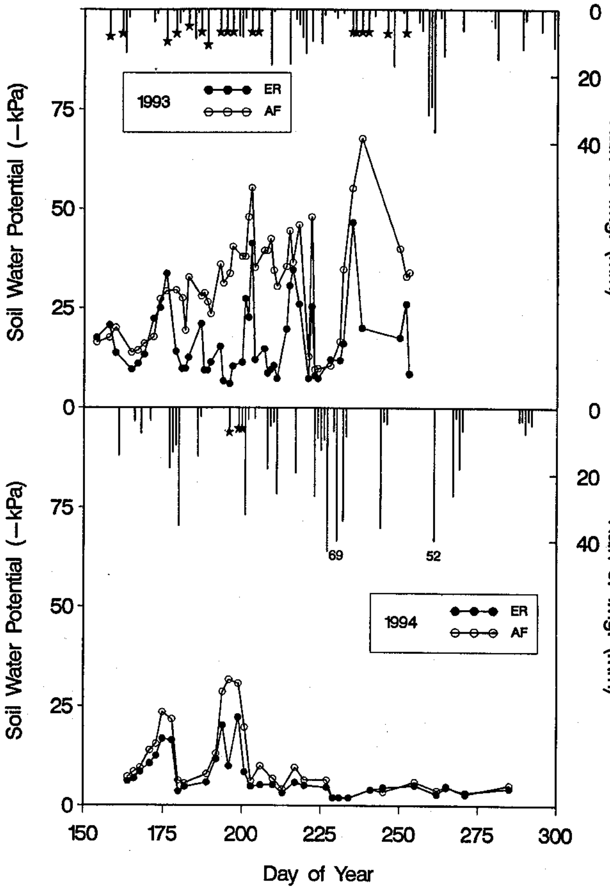


**Figure 3–Soil water potential at the 0.30-m depth and daily rainfall and irrigation amounts for two drip irrigation lateral spacings in cotton during 1993 and 1994. Stars indicate irrigation events.**

Rainfall was well distributed during the 1994 growing season except for a brief period about day of the year (DOY) 190 when 26 mm of irrigation was required. Rainfall was so great during the last half of the 1992 and 1994 growing seasons that soil water conditions were near saturation at times.

Irrigation applications were managed using both the GOSSYM/COMAX model and tensiometers. Irrigation was applied when both GOSSYM/COMAX indicated water stress and tensiometers indicated soil water potential was less than –35 kPa at the 0.3-m depth. The water- and nitrogen-stress indices calculated by the model were used to manage irrigation and N-fertilizer applications in this study. GOSSYM/COMAX was modified to better simulate subsurface drip irrigation because the regular version treats irrigation as rainfall. The model was operated three times each week to determine the need for irrigation and nitrogen. Irrigation applications were normally 6 mm/d and sidedress-N applications were normally 11 kg/ha each week, but higher amounts were applied as needed based on observations and model simulation results. Because GOSSYM/COMAX could not utilize forecast weather data without extensive file editing, future weather inputs were selected from three weather scenarios (normal, hot-dry, and cool-wet) that had been developed from local historical weather data. Daily input requirements for the model are irrigation and rainfall amounts, maximum and minimum temperatures, solar radiation, and wind run, as well as significant cultural practices, such as fertilization.

The irrigation system consisted of individual polyvinylchloride (PVC) pipe manifolds (supply and discharge) for each subplot. Each discharge manifold had removable end caps for flushing. Irrigation laterals (GEOFLOW ROOTGUARD®) had in-line, labyrinth emitters spaced 0.6 m apart, each delivering 1.9 L/h at 140-kPa pressure. Laterals were installed 0.30 m deep using two modified subsoiler shanks mounted on a tool bar. Water was supplied from a well and filtered via a 100-mesh cartridge filter. All irrigation applications were monitored and controlled by a programmable microprocessor-based irrigation controller. A single solenoid valve controlled water and nitrogen applications to all plots for each irrigation-N-treatment combination. Pressure was regulated at about 140 kPa using in-line pressure regulators in the supply manifold for individual plots.

The site was subsoiled in two directions prior to installation of irrigation laterals in 1991, and the seedbed was prepared each year by disking to a depth of about 0.20 m. The RAIN-STD and RAIN-GOS treatments were subsoiled each year. In all years, the surface soil was tested and P, K, lime, and Mn were applied based on soil test results. The preplant broadcast application each year also included 12 kg/ha of N, 11 kg/ha of S, and 0.6 kg/ha of B. Weeds were controlled with a combination of herbicide, cultivation, and hand-weeding. An in-furrow insecticide application was made at planting, and foliar insecticides were applied throughout the season as warranted. A 30-$m^2$ area of two interior rows of each plot was harvested with a spindle picker on 17 October 1991, 12 November 1992, 4 October 1993, and 9 November 1994. Cotton lint yield was calculated from lint percentages determined from subsamples collected from each plot at harvest and ginned on a laboratory saw gin. Lint from the hand-harvested samples was sent to Starlab (Knoxville, Tenn.) for determination of fiber properties.

Because of the rotation in 1992 and 1994, data were analyzed by year. Data were subjected to analysis of variance (ANOVA). Treatment (all four years) and the rotation by treatment interaction (1992 and 1994) sums of squares were partitioned with single degree of freedom contrasts (SAS, 1990). With these contrasts, we compared (1) ER and AF lateral spacings, averaged over all N-application treatments; (2) STD and GOS N treatments, averaged over lateral spacing and RAIN treatments; (3) interaction between lateral spacings (ER or AF) and STD and GOS N-application treatments; (4) rainfed (RAIN) and irrigated (ER and AF), averaged over the STD and GOS treatments; (5) INC and STD N treatments (irrigation only), averaged over lateral spacings; (6) INC and GOS N treatments (irrigation only), averaged over lateral spacings; and (7) STD and GOS N treatments for the RAIN treatment. The interaction between these contrasts and rotation was tested using seven additional contrasts (C8-C14), which provided a total of 14 contrasts.

# Results and Discussion

## Lint Yield

Cotton lint yields and mean squares from analysis of variance for all treatments during the four-year period are shown in tables 4 and 5, respectively. Lint yields were greatest in 1991, ranging from 1570 to 1910 kg/ha, and were lowest in 1992, ranging from 520 to 770 kg/ha (table 4). Lint yields in other years were about double the 1992 yields. Yields ranged from 680 to 1340 kg/ha in 1993 and from 1275 to 1625 kg/ha in 1994.

Low yields in 1992 appear to have been caused by unseasonably low spring temperatures. Night temperatures were less than 15.6°C for 18 of the 20 days following planting in 1992; eight days after planting the temperature fell to 4°C. Conversely, temperatures were less than 15.6°C on only 5, 11, and 8 nights during the same period in 1991, 1993, and 1994, respectively. Temperatures less than 15.6°C can cause cotton seedling stress (Munro, 1987) and can cause morphological and physiological conditions that can affect lint yield (Kittock et al., 1987). In our study, cotton lint yield was increased linearly with seasonal heat unit accumulations during the first 50 DAP ($r^2 = 0.77$) (fig. 4). In a similar manner, cotton lint yield was reduced 80 kg/ha with each day during the first 20 DAP that the minimum daily temperature was less than 15.6°C ($r^2 = 0.79$) (fig. 5). These results indicate that good irrigation and fertilizer management may not overcome the detrimental effects of early season chilling on cotton. Because the chilling effect is measurable and occurs early in the growing season, it may be prudent to modify fertilizer and water management strategies for the remainder of the season in view of the reduced potential yield.

Cotton lint yields were not different for the two lateral spacings in any of the four years (table 5). Irrigation increased yield by 16% in 1992 and 65% in 1993 (table 4). In the other two years, rainfed cotton had similar yield to irrigated. Most of the irrigation (78%) in 1991 was applied during a two-week period starting on 10 September (DOY 253), and had no effect on final lint yield (fig. 3). More irrigation was applied in 1992 than in 1991, especially during the vegetative and early fruiting periods. Extremely wet soil conditions caused by excessive rainfall during a period of about eight days following DOY 225 could have caused root oxygen stress and loss of bolls, and could have reduced the fruiting period length by 7 to 10 d. Rainfall distribution was poor in 1993, with only 85 mm (25% of total) occurring during the first half of the growing season. The small amount of irrigation applied early in the 1994 growing season did not affect yield.

Growing-season reference evapotranspiration (Et) values, calculated by the modified Jensen-Haise method (Jensen et al., 1970; Jensen and Haise, 1963), for all years of the study are reported in figure 6. There is general agreement between seasonal Et and irrigation applied each year. Seasonal Et was greatest in 1993 when the seasonal irrigation amount was greatest and rainfall was lowest. Cumulative Et values for 1991 and 1992 were similar and

**Table 4. Cotton lint yields for two irrigation lateral spacings, two crop rotations, and three N-sidedress treatments in a cotton experiment on a southeastern Coastal Plain soil during 1991-1994**

| Lateral Spacing | Crop Rotation | 1991 GOS | 1991 INC | 1991 STD | 1992 GOS | 1992 INC | 1992 STD | 1993 GOS | 1993 INC | 1993 STD | 1994 GOS | 1994 INC | 1994 STD |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | kg/ha | | | | | | | | | | | |
| AF* | C/C | 1725 | 1755 | 1595 | 600 | 645 | 550 | 1145 | 1300 | 1155 | 1400 | 1475 | 1345 |
| ER | C/C | 1610 | 1795 | 1815 | 655 | 535 | 725 | 1145 | 1175 | 1340 | 1350 | 1275 | 1520 |
| RAIN | C/C | 1910 | --- | 1570 | 520 | --- | 520 | 815 | --- | 680 | 1460 | --- | 1350 |
| AF | P/C | --- | --- | --- | 750 | 630 | 730 | --- | --- | --- | 1535 | 1515 | 1455 |
| ER | P/C | --- | --- | --- | 770 | 755 | 710 | --- | --- | --- | 1520 | 1550 | 1625 |
| RAIN | P/C | --- | --- | --- | 620 | --- | 690 | --- | --- | --- | 1405 | --- | 1540 |

* Treatment codes are the same as defined in table 3.

**Table 5. Mean squares from analysis of variance for cotton lint yield and fiber properties**

| Source | Elon-gation | Span Length 50% | Span Length 2.5% | Strength $\times 10^2$ | Micro-naire | Yield | Source | Elon-gation | Span Length 50% | Span Length 2.5% | Strength $\times 10^2$ | Micro-naire | Yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1991** | | | | | | | **1993** | | | | | | |
| Rep | 0.2 | 0.3 | 0.2* | 1.0 | 0.17 | 155905 | Rep | 0.2 | 0.4 | 0.9* | 1.0 | 0.05 | 327199 |
| Treatment (TMT) | 0.7* | 0.2 | 0.2† | 1.4* | 0.16 | 57949 | TMT | 0.1 | 0.2 | 0.3 | 0.4 | 0.02 | 210671† |
| C1: ER vs AF | 3.4† | 0.9* | 0.1 | 0.3 | 0.16 | 13669 | C1 | 0.3 | 0.1 | 0.0 | 0.1 | 0.05 | 2173 |
| C2: STD vs GOS | 0.5 | 0.0 | 0.0 | 0.5 | 0.00 | 47147 | C2 | 0.1 | 0.0 | 0.0 | 0.4 | 0.01 | 2876 |
| C3: C1*C2 | 0.1 | 0.1 | 1.0† | 0.2 | 0.12 | 112060 | C3 | 0.0 | 1.0* | 0.2 | 0.0 | 0.00 | 35032 |
| C4: RAIN (RN) vs IR | 0.5 | 0.0 | 0.0 | 1.7 | 0.65† | 16376 | C4 | 0.0 | 0.1 | 1.1* | 0.9 | 0.07 | 1071369† |
| C5: INC vs STD | 0.6 | 0.0 | 0.0 | 7.0† | 0.14 | 19152 | C5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 215 |
| C6: INC vs GOS | 0.1 | 0.0 | 0.3* | 5.0† | 0.18 | 44642 | C6 | 0.0 | 0.0 | 0.0 | 0.8 | 0.00 | 35922 |
| C7: STD vs GOS, RN | 0.3 | 0.0 | 0.1 | 0.5 | 0.00 | 229609* | C7 | 0.2 | 0.0 | 0.4 | 0.0 | 0.01 | 38385 |
| Error | 0.2 | 0.1 | 0.04 | 0.5 | 0.07 | 35756 | Error | 0.1 | 0.1 | 0.2 | 1.0 | 0.04 | 26992 |
| **1992** | | | | | | | **1994** | | | | | | |
| Rep | 0.1 | 0.5* | 0.6 | 1.0 | 0.00 | 20546 | Rep | 0.1 | 0.5 | 1.0 | 21.0† | 0.05 | 153085 |
| Rotation (ROT) | 0.0 | 0.1 | 0.3 | 0.3 | 0.01 | 217215 | ROT | 3.3* | 0.1 | 0.0 | 0.1 | 0.30 | 233244 |
| Error A | 0.1 | 0.0 | 0.2 | 0.9 | 0.06 | 58948 | Error a | 0.1 | 0.2 | 0.5 | 0.7 | 0.36 | 288999 |
| TMT | 0.2 | 0.2 | 0.4 | 0.8 | 0.12 | 17763 | TMT | 0.1 | 0.4* | 0.3 | 1.1 | 0.10* | 24921 |
| C1: ER vs AF | 0.0 | 0.1 | 0.6 | 2.4* | 0.00 | 16520 | C1 | 0.0 | 0.3 | 0.1 | 0.2 | 0.11 | 4936 |
| C2: STD vs GOS | 0.1 | 0.2 | 0.4 | 0.5 | 0.07 | 572 | C2 | 0.0 | 0.0 | 1.2* | 0.0 | 0.14 | 9587 |
| C3: C1*C2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.01 | 5701 | C3 | 0.4 | 0.0 | 0.0 | 0.3 | 0.17* | 84813 |
| C4: RAIN (RN) vs IR | 1.1† | 0.3 | 0.8 | 0.5 | 0.60† | 92326* | C4 | 0.0 | 0.0 | 0.0 | 0.1 | 0.07 | 9376 |
| C5: INC vs STD | 0.0 | 0.0 | 0.0 | 0.6 | 0.04 | 10978 | C5 | 0.4 | 0.1 | 0.0 | 0.0 | 0.00 | 8265 |
| C6: INC vs GOS | 0.1 | 0.3 | 0.4 | 1.0 | 0.00 | 14696 | C6 | 0.1 | 0.9* | 0.1 | 0.0 | 0.03 | 81 |
| C7: STD vs GOS, RN | 0.1 | 0.1 | 0.0 | 0.8 | 0.04 | 4812 | C7 | 0.2 | 1.5† | 1.3* | 0.1 | 0.14 | 802 |
| ROT*TMT | 0.1 | 0.2 | 0.4 | 0.8 | 0.01 | 15376 | ROT*TMT | 0.3 | 0.2 | 0.3 | 0.5 | 0.04 | 19256 |
| C8: ROT*C1 | 0.0 | 0.0 | 0.1 | 0.0 | 0.00 | 603 | C8 | 0.4 | 1.2* | 0.0 | 0.6 | 0.04 | 23648 |
| C9: ROT*C2 | 0.4 | 0.0 | 0.1 | 0.0 | 0.00 | 1285 | C9 | 0.2 | 0.1 | 0.0 | 0.2 | 0.00 | 8059 |
| C10: ROT*C3 | 0.1 | 0.4 | 0.2 | 1.2 | 0.00 | 17026 | C10 | 0.1 | 0.3 | 0.3 | 0.0 | 0.04 | 908 |
| C11: ROT*C4 | 0.0 | 0.2 | 1.8* | 0.4 | 0.02 | 974 | C11 | 0.0 | 0.1 | 0.3 | 0.8 | 0.03 | 10290 |
| C12: ROT*C5 | 0.0 | 0.7 | 0.9 | 1.2 | 0.00 | 770 | C12 | 0.6 | 0.2 | 0.4 | 0.3 | 0.04 | 4308 |
| C13: ROT*C6 | 0.1 | 0.5 | 0.8 | 2.1* | 0.00 | 4207 | C13 | 0.0 | 0.1 | 0.2 | 0.4 | 0.02 | 16 |
| C14: ROT*C7 | 0.2 | 0.1 | 0.3 | 0.3 | 0.02 | 4911 | C14 | 0.3 | 0.0 | 0.1 | 0.1 | 0.00 | 58841 |
| Error b | 0.1 | 0.2 | 0.3 | 0.4 | 0.03 | 16261 | Error b | 0.2 | 0.2 | 0.3 | 0.9 | 0.04 | 39911 |

Values with *, † indicate significant difference ($P \geq 0.05$, 0.01, respectively) by single-degree of freedom contrast.

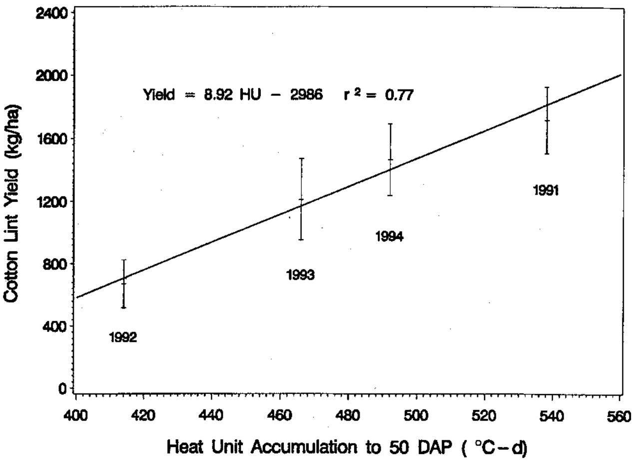


**Figure 4–Relationship between cotton lint yield and annual accumulated heat units during the first 50 DAP for 1991-1994. Heat units were calculated by summing $[(T_{max} + T_{min})/2] - 15.6°C$.**

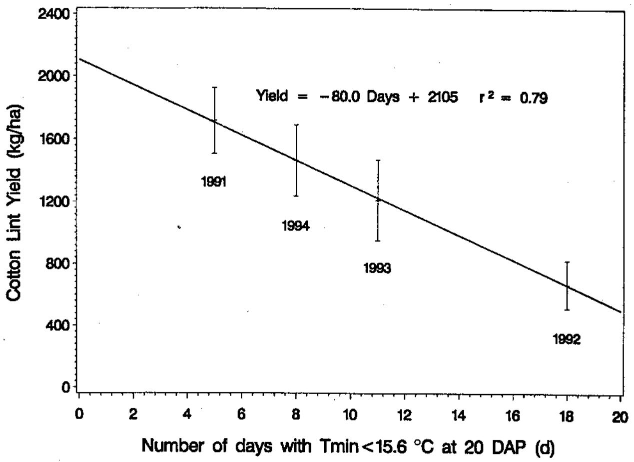


**Figure 5–Relationship between cotton lint yield and number of days during the first 20 DAP with daily minimum temperature less than 15.6°C each year for 1991-1994.**

mid-range for the four years. Seasonal irrigation in 1992 ranked second among the four years and was slightly greater than that for 1991. Cumulative Et was lowest in 1994 when rainfall was moderately high, distribution was good, and the least amount of irrigation was required. Consequently, the relative magnitudes of seasonal Et and irrigation amounts among years are similar.

Nitrogen management using the GOSSYM/COMAX model generally attained equivalent cotton yield with less fertilizer N. Lint yields were not significantly different among the three N-application methods for any of the four years. In each of the four years, the GOS treatment received 45 kg/ha less fertilizer N than the other two treatments, which reflected state recommendations, and lint yields were not different. Previously, Bauer et al. (1993) found that 56

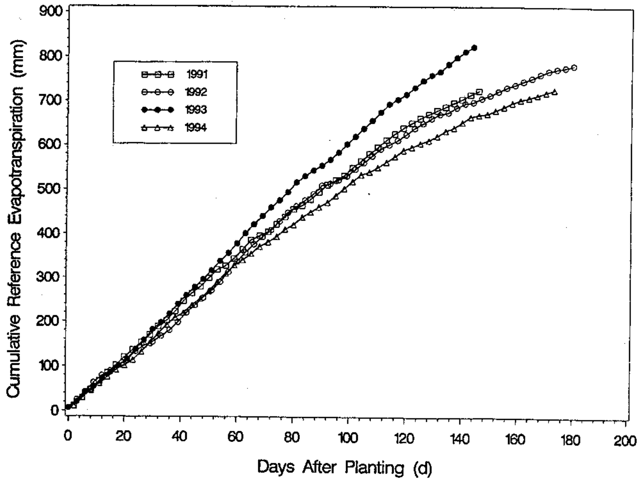


**Figure 6–Reference evapotranspiration (Et) during the growing season (planting to harvest) calculated by modified Jensen-Haise method for Florence, S.C., 1991-1994.**

kg/ha was the optimum fertilizer-N rate during a three-year study where yields were similar to this study. N accumulation by the cotton plant and residual soil N for this study indicate that irrigation and N-fertilizer treatments had a greater effect on seed-N accumulation and potential net addition of N to the soil than on lint yield (P. G. Hunt, personal communication, Florence, S.C., 13 November 1996). Leaf petiole and leaf blade nitrogen concentrations for all treatments in this study were above the deficiency range at first bloom each year (P. J. Bauer, personal communication, Florence, S.C., 10 July 1996). Lint yield for the RAIN-GOS treatment was greater than that for the RAIN-STD in 1991, but was similar in other years (tables 4 and 5). This result is similar to that for the irrigated treatments, where similar lint yields were produced with 45 kg/ha less N fertilizer, although N fertilizer was not managed separately for the rainfed treatments. While state N-fertilizer recommendations for rainfed cotton appear adequate, the use of GOSSYM/COMAX may allow reduction of N-fertilizer applications if other factors limit yield potential for that year.

### Fiber Properties

Irrigation did not have a consistent effect on any fiber property (table 6). Elongation was greater in the irrigated cotton than in the rainfed only in 1992. Span length (2.5%) was greater for the irrigated treatment only in 1993 (table 6). Fiber strength was not affected by irrigation in any year. Differences in micronaire between irrigated and rainfed treatments occurred in the first two years of the study. In 1991, the irrigated treatments had higher micronaire than the rainfed, but the result was opposite in 1992. It is unclear why micronaire was lower for the rainfed cotton in 1991. In 1992, an in-depth analysis of fiber properties was performed on a subset of these plots. Those results suggested that irrigation caused a higher incidence of motes (undeveloped fibers) in bolls at most main-stem node positions within the canopy that year (Bradow et al., 1996). The higher elongation for irrigated cotton that year is consistent with a higher immature fiber content. The lack of difference in micronaire between irrigated and rainfed treatments in 1993 was surprising because irrigation increased lint yield in both 1992 and 1993, and differences in micronaire occurred only in 1992. Further study is needed of the impact of

**Table 6. Effect of irrigation on cotton fiber properties**

| Year | Irrigation* | Elongation (%) | Span Length 50% (mm) | Span Length 2.5% (mm) | Strength (kN m/kg) | Micronaire |
|---|---|---|---|---|---|---|
| 1991 | Yes | 7.8 | 13.7 | 29.2 | 199 | 3.91‡ |
| | No | 7.7 | 13.7 | 29.2 | 201 | 3.62 |
| 1992 | Yes | 7.5‡ | 14.5 | 29.2 | 201 | 3.83‡ |
| | No | 7.3 | 14.7 | 30.0 | 201 | 4.14 |
| 1993 | Yes | 7.6 | 14.2 | 30.0† | 209 | 4.27 |
| | No | 7.5 | 14.2 | 29.5 | 214 | 4.39 |
| 1994 | Yes | 7.6 | 14.0 | 29.2 | 213 | 3.99 |
| | No | 7.7 | 13.7 | 29.2 | 211 | 3.95 |

* Means are averaged over both lateral spacings and all N levels within each irrigation level.

†, ‡ Indicate significant difference ($P > 0.05$, 0.01, respectively) by single-degree of freedom contrast.

supplemental irrigation on fiber characteristics that determine micronaire.

Some contrasts that involved rotation, irrigation lateral spacing, and N-application method were significant for some fiber properties in each year of the study, but the influence of lateral spacing and N method was small and inconsistent from year to year (table 5). These N results agree with Pettigrew et al. (1996) who found that additional N above the recommended rate did not influence fiber properties.

### Soil Matric Potential

Tensiometer data for the 0.30-m depth in both lateral spacings during 1991-1994 are shown in figures 2 and 3. Irrigation initiation at the soil water potential (SWP) value of –35 kPa was selected with the goal of never allowing SWP values at the 0.30-m depth to decrease below –50 kPa. In 1991, SWP values for both lateral spacings were always greater than –50 kPa but on a few occasions did reach –35 kPa, mostly during the early growing season. Values were greater than –25 kPa for much of the last half of that growing season. In 1992, the –50 kPa target was missed only twice for both lateral spacings. Large rainfall amounts during the last half of the 1992 growing season (starting at DOY 225) caused SWP values to be greater than –10 kPa much of the late season. The soil was so wet during the period DOY 225-240 that tensiometer data could not even be collected. In 1993, SWP values were similar to those in previous years, but differences between values for the ER and AF treatments were more defined. No differences in leaf water potential were measured between the two lateral spacings for several periods when water stress was occurring (P. J. Bauer, personal communication, Florence, S.C., 10 July 1996). Soil water potential values for the ER spacing were consistently greater than those for the AF spacing, indicating that the irrigation water was placed nearer the cotton rows (and tensiometers). However, except for two instances, SWP values for the AF spacing remained above –50 kPa for the entire growing season. In 1994, SWP values were greater than –25 kPa except for one period near DOY 190 when values for the AF spacing reached –35 kPa for 6 to 8 days. Otherwise, SWP values were similar for both lateral spacings and were greater than in the other years of the study, especially during the last half of the growing season when several large rainfall events caused SWP values to be greater than –10 kPa at times.

These results suggest that in the southeastern USA, alternate-furrow spacing (2-m spacing) of subsurface drip irrigation laterals appears to be adequate for irrigating cotton on coarse-textured soils. Significant savings (about 30%) in irrigation system cost can be achieved by using the wider lateral spacing (AF). Even wider lateral spacings (3-4 m) might be appropriate for some situations, but French et al. (1985) found that cotton yields in Arizona were 30% lower when lateral spacing was increased from 2 m to 3 m. However, the risk of reduced yield for the wider spacing in years with extreme drought may be acceptable in the southeastern Coastal Plain, and may be the most profitable spacing over the long term. On a similar soil to this experiment, Camp et al. (1989) found that surface drip irrigation spaced 1.5 m apart caused uneven crop growth during an early-season drought following germination and plant establishment for corn planted in rows 0.76 m apart. This wide spacing led to reduced plant height and biomass, and a 10% reduction in grain yield in one of three years. Plant population was not affected because rainfall and soil water content were sufficient for germination and plant establishment. One relatively low risk of the subsurface drip irrigation system in humid areas is that it may not provide the uniform soil surface wetting required for seed germination and plant establishment, especially for wide spacings when rainfall is absent. Generally, subsurface drip irrigation systems do not provide uniform soil wetting on or near the soil surface, especially in coarse-textured soils during extended drought.

## Summary and Conclusions

Irrigation increased cotton lint yields in two of four years. Yields for the two lateral spacings were not different in any of the four years. No differences among yields for the three N-sidedress treatments occurred, even though the GOS treatment received 45 kg/ha less nitrogen than the other treatments. Fiber properties were similar for the four years of this study. Irrigation lateral spacing and N-fertilizer method significantly affected some fiber properties in all years, but the effects were small and inconsistent. Further study is needed of the impact of supplemental irrigation on fiber properties, especially micronaire. Based on these results, it appears that the wider subsurface drip irrigation lateral spacing (AF) is as effective as placement under every row (ER) on southeastern Coastal Plain soils. Good irrigation and fertilizer management may not overcome the detrimental effects of early season chilling on cotton. These results indicate that profitability for cotton using subsurface drip irrigation in this region may be substantially better than expected because of longer system life, lower system cost, and lower N fertilizer applied with the GOS nitrogen treatment. The lower N requirement suggests that greater fertilizer-N efficiency and reduced potential N losses to the environment are possible. Consequently, the AF-GOS management system is preferred because of the lower irrigation system and N-fertilizer cost, and the reduced environmental risk.

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